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Modeling the Effects of Maternal Nutritional Status and Socioeconomic Variables on the Anthropometric and Psychological Indicators of Kenyan Infants From Age 0–6 Months

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ABSTRACT This paper presents a comprehensive empirical analysis of the factors affecting growth and psychological development of over 100 infants from birth to age 6 months in the Embu region of Kenya. The analysis was divided into four parts. First, infants' birth weight, and length and head circumference as measured few days after birth, were modeled using multiple regression models. Maternal prepregnancy body mass index (BMI), gestation period, and parity were associated with infants' anthropometric measurements ($P < 0.05$). Second, the scores on seven clusters of the Brazelton Neonatal Behavioral Assessment Scale were explained by health and socioeconomic indicators. While the models had poor predictive power, the scores were comparable to those reported in the literature for Puerto Rican and African American infants. The third part of the analysis modeled infant growth between 1–6 months by analyzing longitudinal data on length, head circumference, and weight. Dynamic models were postulated for the effects of nutritional, socioeconomic, and environmental factors and morbidity on anthropometric variables. The results showed that infants' calcium intakes were positively associated with length ($P < 0.05$). Maternal BMI and hemoglobin concentration were positively associated with infant weight ($P < 0.05$); infant morbidity was negatively associated with weight ($P < 0.05$). Lastly, the infants' scores at 6 months on the Bayley Motor Scale and on eight items from the Bayley Infant Behavior Record were explained using anthropometric, socioeconomic, and psychological variables. The infants' arm circumference and intake of protein were significant predictors of scores on the Bayley Motor Scale. In addition, time spent by the mother talking to the infant was positively associated with the scores on the Bayley Infant Behavior Record. The empirical results have implications for identifying vulnerable children in developing countries. Am J Phys Anthropol 111:89–104, 2000. © 2000 Wiley-Liss, Inc.

A large number of children in developing countries are undernourished (Food and Agriculture Organization, 1996). Undernutrition suffered during the formative years affects individuals' activities over their entire life span. Different disciplines are therefore concerned with the effects of undernutrition at different stages of life. Physiologists, for example, study the physical work capac-

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ity of undernourished adults in developing countries. Studies have shown that adults with a poor nutritional status (low body mass index (BMI)) have lower oxygen uptake and reduced physical work capacity (Spurr, 1983). Similarly, field studies have shown that anemic individuals take longer to complete agricultural tasks (Basta et al., 1979). Because economists are concerned with raising labor productivity, the link between nutrition and adult productivity has been discussed in the economics literature (Leibenstein, 1959; Bhargava, 1997; Strauss and Thomas, 1998).

Although the link between nutrition and labor productivity is an important one, food policies can improve adult productivity in a limited way, in comparison with the benefits from targeting children. For example, while one can obtain higher agricultural output per worker by providing anemic individuals with iron-fortified foods (Basta et al., 1979), it would be more difficult to train such workers into skilled occupations. For creating a well-trained labor force, it is necessary that, starting from a very early age, children receive adequate quantities of energy, protein, and micronutrients (Pollitt, 1993; Pollitt et al. 1993; Scrimshaw, 1998); education and health environments play a vital role in cognitive development (Bhargava, 1998).

The early development of children has been studied by many researchers in nutrition and psychology (Waterlow, 1988; Rovee-Collier and Lipsitt, 1992; Pollitt et al., 1993; Grantham-McGregor, 1995). Because the human brain shows rapid growth during the first 2 years, a diet high in protein and micronutrients is likely to facilitate brain development (Monckeberg, 1975). Since these nutrients are found in relatively expensive foods, maintaining an adequate supply of vital nutrients in a rather short time interval during childhood presents a challenge to policy makers in international organizations and national governments.

The task of identifying young children whose brain development might have been compromised by nutrient deficiencies is complicated by several factors. First, psychological tests for infant development such as the Bayley tests are known to have poor reliability; infants tested a week apart can score quite differently on the same components of the test (Horner, 1988). Second, while the rate of linear growth of children in developing countries begins to falter at an early age (Waterlow, 1994), comparisons using psychological measures are ambiguous because neurological development is a complex process, and many of its dimensions cannot be quantified. Modeling the interrelationships between children's anthropometric measures and the scores on psychological tests can provide useful insights.

The purpose of this paper was to develop a comprehensive empirical model for the proximate determinants of physical and mental development of infants in the Embu region of Kenya. The analysis considered the anthropometric and psychological indicators of development in the period from birth to age 6 months and used appropriate statistical techniques when modeling the effects of socioeconomic, nutritional, and environmental variables on infant development. First, the proximate determinants of birth weight, and length and head circumference as measured a few days after birth, were modeled; nutritional, socioeconomic, and demographic variables were used in the multiple regression analysis. Second, the scores obtained by the infants within a week of birth on the Brazelton Neonatal Behavioral Assessment Scale (NBAS) (Brazelton, 1984) were modeled using similar explanatory variables. Third, the dynamics of growth in the period of 1–6 months were modeled in a longitudinal framework, using six repeated observations. The principle of maximum likelihood was used to estimate parameters of dynamic models for length, head circumference, and weight; the infants' z-scores for weight-for-age were also modeled in a dynamic framework. Finally, the scores obtained on the Bayley Motor Scale and eight items from the Bayley Infant Behavior Record (Bayley, 1969) were modeled using regression analysis.

MATERIALS AND METHODS

Subjects

The data were derived from surveys sponsored by the U.S. Agency for International Development in 1984–1985 in the Embu region of Kenya (Sigman et al., 1989). Of the 2,059 households in the region, households

were selected to participate in the study if there was a toddler (approximately 18 months old) or a school-age child (6–9 years) present; households were also included if the lead female in the household was pregnant but had not completed the first trimester. A household was ineligible if the lead female was over 40 years old, or her last pregnancy occurred over 5 years ago, or if a child had been born within the previous 10 months. Thus, 292 households were eligible. Over 100 infants born during the observation period were followed longitudinally from birth until age 6 months. The study was approved by a Human Subjects Committee of the University of California, Los Angeles (Neumann et al., 1992).

Anthropometry and psychological measurement

The infants were weighed at birth and, within a few days after birth, measurements were taken on length, head circumference, and arm circumference; skinfold thicknesses were measured at triceps, biceps, and subscapular sites. Afterwards, anthropometric variables were measured every month. Typically, two sets of measurements were taken by different enumerators; correlations between the measurements were close to 0.95.

Trained observers completed the Brazelton NBAS few days after birth (Brazelton, 1984). The scale consisted of two parts. First, there were elicited responses on 18 items that were scored from “low” to “high” on a scale of 1–3. The second part of the scale consisted of 27 behavioral items that were scored on a scale of 1–8. Because higher scores on behavioral items did not indicate better performance, the scores were redefined on a progressive scale (Lester et al., 1982). Further, using the progressive scoring system, the 27 behavioral items were grouped into six clusters: Habituation, Orientation, Motor, Range of State, Regulation of State, and Autonomic Stability (Lester et al., 1982); the mean score on the 27 items was also used as an indicator. The number of abnormal responses on the 18 items in the first part of the test constituted the score on the seventh (Reflex) cluster, where higher scores indicated worse performance.

The test for motor development given at 6 months consisted of 33 items selected from the Bayley Motor Scale (Bayley, 1969). There were no ambiguities in scoring in this component of the test because the scores were dichotomous (infants either passed or failed the items). Motor development was defined by the number of items on which infants passed the test; this score was used as a dependent variable in the fourth part of the analysis. Interobserver reliability of the scores was high (Whaley et al., 1998).

For the analysis of data from the Bayley Infant Behavior Record, eight items were selected: Endurance, Activity, Banging Toys, Manipulating, Body Motion, Energy and Coordination, Coordination of Gross Muscle Movement, and Coordination of Fine Muscle Movement. For 6-month-old infants, it was appealing to focus on items that would be less affected by within-infant variability. For example, the score on Responsiveness to Examiner was more likely to be affected by swings in infant moods than the scores on Endurance or Energy and Coordination. For a subset of 22 infants, the interobserver reliability ranged from 0.72–0.86 for factors extracted using principal components analysis (Whaley et al., 1998).

Infant-caregiver interaction was assessed using a time-sampling procedure. The proportion of time for which the mother, an adult, or an older sibling looked, held, touched, and talked to the infant in a 30-min period was recorded at 60-day intervals. Thus, three repeated observations were available for each infant on four interaction variables (look, hold, touch, and talk). The observations were subsequently averaged over time to produce mean levels of the interaction variables for the 6-month observation period; averaging also reduced the within-subject variation in the measurement of care-giving.

Measurement of nutritional, socioeconomic, and demographic variables and morbidity

Length of the gestation period was estimated by the method of Dubowitz and Dubowitz (1977). Breast-feeding patterns of the infants were investigated in the questionnaire. Mothers were asked about duration and frequency of breast feeding. Most infants received supplemental foods after a

few months. The intakes of supplemental foods were converted into intakes of 41 nutrients, using food composition tables (Murphy et al., 1991). Sicknesses of the infants were recorded on a weekly basis. Each month, the numbers of days for which an infant was sick with different symptoms were combined to form an index of morbidity (Bhargava, 1994, 1999). A separate index was created for diarrhea, though the incidence of diarrhea was low.

For each infant, detailed information was available on the nutritional status of the mother before and after the birth. Measurements on weight, arm circumference, and skinfold thicknesses at biceps, triceps, subscapular, suprailiac, abdomen, and thigh sites were taken every month (similar measurement were taken on the fathers). Maternal height and head circumference were measured once during the observation period. Maternal nutrient intakes were assessed on a monthly basis, using the 24-hr recall method and by weighing certain food portions on the day of the survey. Sicknesses were recorded on a fortnightly basis; an index of morbidity was constructed for the mothers. Blood analyses measured the hemoglobin concentration and white blood cell count, at least once during the observation period; intensity of hookworms in the stool was measured once.

Education levels of the parents were available in the data; parents took the revised version of Wechsler's Adult Intelligence Scale (Wechsler, 1981) and Raven's Progressive Matrices (Raven, 1965). Sanitation and hygiene practices of the household were recorded. An index of socioeconomic status was constructed on the basis of household possessions and cash income. The data covered more than 100 infants. However, the number of observations used to estimate various models differed because of missing observations on the explanatory variables in the models. For further details of the study design, see Neumann et al. (1992).

A framework for modeling anthropometric and psychological indicators: proximate determinants of birth weight, length, and head circumference

A majority of pregnant women in developing countries have themselves suffered from undernutrition during childhood, which can limit their capacity to produce healthy infants. Episodes of undernutrition and morbidity during pregnancy can adversely affect fetal development and hinder postnatal growth. For understanding the effects of undernutrition on child development, it is important to begin with an analysis of factors contributing to intrauterine growth retardation.

Babies born in developing countries are typically shorter, weigh less, and have a smaller head circumference than their counterparts in affluent societies (Falkner et al., 1994). In some cases, however, head circumference is proportionately less reduced; such infants have shown a greater propensity for catch-up growth (Miller, 1992). This could be due to better maternal nutrition in earlier phases of pregnancy. Further, maternal nutritional status is likely to deteriorate with parity in developing countries because the diet is often deficient in energy, protein, and micronutrients necessary to sustain energy expenditures for subsistence activities (Bhargava, 1997). Birth outcomes would therefore depend on the maternal prepregnancy nutritional status and the timing of undernutrition and sicknesses during the pregnancy. Because the biological relationships between maternal nutritional status and fetal development are complex (Tanner, 1989), epidemiological investigation can provide useful insights.

There have been several studies analyzing the effects of maternal undernutrition on outcomes such as birth weight (Milner, 1988). For the Kenyan data analyzed in this paper, Neumann and Harrison (1994) reported positive correlations between maternal size (height and weight) and birth weight. However, the data contain information on maternal hemoglobin concentration, hookworm infestation, and morbidity that are measures of health status (Mata, 1978; Scrimshaw, 1998). Moreover, maternal micronutrient intakes and demographic variables such as number of preceding live births are potentially important predictors of infant weight, length, and head circumference.

Modeling the scores on the Brazelton Neonatal Behavioral Assessment Scale

Development of the central nervous system is a complex process, and it is often difficult to assess the effects of undernutrition on neurological development, even using advanced techniques (Levitsky and Strupp, 1995). Thus, researchers often use head circumference as a proxy for brain growth, even though the time profiles of changes in brain mass and head circumference are known to differ (Dobbing and Sands, 1978). It is useful to seek additional measures of infant development for identifying vulnerable children early in life (Bornstein and Lamb, 1992).

The Brazelton NBAS is a widely used instrument for evaluating infant behavior (Brazelton, 1984). However, the scores on different test items have different interpretations. Lester et al. (1982) redefined the NBAS scores on a progressive scale; six clusters, namely, Habituation, Orientation, Motor, Range of State, Regulation of State, and Autonomic Stability have been suggested, using principal components analysis. This grouping has the advantage of reducing within-infant variation; the scores on clusters are amenable to multivariate modeling.

Simple correlations between explanatory variables and scores on the Brazelton NBAS clusters, however, are often ambiguous. For example, Oyemade et al. (1994) reported that the score of African American infants on the Motor cluster was negatively correlated with "high partner interaction," whereas it was positively correlated with "high degree of happiness of spousal partner." Similarly, certain other correlations between the scores on NBAS clusters and explanatory variables reported by these authors were difficult to interpret. A systematic approach would be to introduce a set of potentially relevant explanatory variables into a multivariate model explaining the scores; important predictors can be retained on the basis of statistical tests.

Dynamic modeling of length, head circumference, and weight in the period of 1–6 months

The first 2 years of a child's life are critical from the standpoint of physical growth and brain development; linear growth begins to falter in undernourished populations within few weeks after birth (Adair et al., 1993; Hernandez-Beltran et al., 1996). Longitudinal studies relating maternal nutritional and health status and environmental factors to anthropometric measurements of infants can provide insights into the causes of growth retardation. It would be useful to model the dynamics of infant weight, length, and head circumference in the period from 1–6 months. Thus, for example, the effects of maternal nutritional status on nutrient composition and volume of breast milk have been investigated in field studies (e.g., Jelliffe and Jelliffe, 1978; Brown et al., 1986; Prentice et al., 1994). Because breast milk is the primary source of nourishment for infants in the age group 1–6 months, indicators of maternal nutritional status such as BMI, arm circumference, protein intakes, and hemoglobin concentration are potentially important factors explaining infant growth. Furthermore, unobserved between-infant differences are important for modeling growth because they partly reflect genetic differences and also environmental factors that cannot be controlled for. Models ignoring unobserved differences can yield inconsistent parameter estimates, especially in dynamic formulations where anthropometric measurements in a given period depend on past measurements.

Assuming that n infants were observed 6 times at monthly intervals, the system of equations estimated for length (LE), head circumference (HD), and weight (W) is given by equations (1–3) ($i = 1, \ldots, n$; $t = 2, \ldots, 6$):

$$LE_{it} = \sum_{j=1}^{m^1} z_{ij}\,\gamma_j + \sum_{j=1}^{p^1} x_{ijt}\,\zeta_j + \alpha_1\,LE_{it-1} + \lambda_1\,M_{it} + u_{1it} \tag{1}$$

$$HD_{it} = \sum_{j=1}^{m^2} z_{ij}\,\kappa_j + \sum_{j=1}^{p^2} x_{ijt}\,\mu_j + \alpha_2\,HD_{it-1} + \lambda_2\,LE_{it} + \lambda_3\,M_{it} + u_{2it} \tag{2}$$

$$W_{it} = \sum_{j=1}^{m^3} z_{ij}\,\phi_j + \sum_{j=1}^{p^3} x_{ijt}\,\psi_j + \alpha_3\,W_{it-1} + \lambda_4\,LE_{it} + \lambda_5\,AM_{it} + \lambda_6\,M_{it} + u_{3it} \tag{3}$$

Here, the z's and x's are, respectively, time-invariant and time-varying explanatory variables; the coefficients are denoted by Greek letters. Background variables such as maternal height that did not change during the survey period were included in the z's. Nutrient intakes, that changed with the month, were included in the x's. M and AM were, respectively, an index of infant morbidity and arm circumference. While M and AM were time-varying, they were written separately to facilitate the discussion of the model.

The system in equations (1–3) embodied several interrelationships between the anthropometric indicators. For example, infant weight was explained by length because the latter approximates skeletal size (Ehrenberg, 1968; Tanner, 1986; Cole, 1991). Moreover, arm circumference was included in the model because it is a proxy for lean body tissue (Bhargava, 1999). While weight would respond quickly to shortfalls in energy intake and sickness spells, the inclusion of length and arm circumference as explanatory variables controlled for many factors that could not be easily observed. Moreover, since current weight would depend on weight in the previous period, the model for weight in equation (3) was a dynamic relationship. An alternative to modeling the dynamics of infant weight by equation (3) would be to model the z-scores for weight-for-age. This approach was suggested by a reviewer and was also explored using the Kenyan data on infants in the period from 1–6 months.

Modeling the scores on Bayley Motor Scale and Bayley Infant Behavior Record

In affluent societies, children in the age group 3–24 months are sometimes examined on the Bayley Motor Scale and the Bayley Infant Behavior Record (Bayley, 1969). This is less common in poor countries, in part because of the costs associated with testing. From a policy viewpoint, it is important to identify vulnerable children early in life. Thus, a model for the proximate determinants of scores on Bayley scales at 6 months would be of interest. Because the infants were previously examined on the Brazelton NBAS, one can also investigate the predictive power of NBAS for the scores on the Bayley scales.

The scores on eight items selected from the Bayley Infant Behavior Record were Endurance, Activity, Banging Toys, Manipulating, Body Motion, Energy and Coordination, Coordination of Gross Muscle Movement, and Coordination of Fine Muscle Movement. Proximate determinants of the scores were analyzed using regression models. Scores on the last two items were transformed so that higher scores implied better coordination (Wolf and Lozoff, 1985). An alternative approach would be to use principal components analysis for clustering items (Kaplan-Estrin et al., 1994). However, the clusters are often difficult to interpret.

Econometric procedure

For multiple regression models, the procedure PROC REG by SAS (1997) was used to estimate model parameters. Dynamic models for infant length, head circumference, and weight given by equations (1–3), were estimated by the principle of maximum likelihood (Bhargava and Sargan, 1983). A computer program was developed in Fortran to compute the likelihood functions; model parameters were estimated by optimizing the likelihood function, using the routine E04 JBF from the Numerical Algorithm Library (NAG, 1989). The estimation theory assumed that initial observations of the dependent variables were *endogenous* variables (correlated with the errors) and that the errors (u_{it}) were independent across infants but correlated over time with a positive definite variance covariance matrix. The random effects model is a special case:

$$u_{it} = \delta_i + v_{it} \tag{4}$$

where δ's are infant-specific, normally distributed random variables and v's are independently normally distributed random variables. The exogeneity hypothesis of zero correlation between n_2 time-varying regressors (x_2) and random effects was tested by likelihood ratio tests. With six time observations in the data set, the statistic was asymptotically distributed as a chi-square variable with $6n_2$ degrees of freedom.

TABLE 1. Regression models explaining infant birth weight and length and head circumference measured shortly after birth by maternal nutritional status and demographic characteristics[1]

	Birth weight (kg)		Length (cm)		Head circumference (cm)	
Dependent variable	Coefficient	SE	Coefficient	SE	Coefficient	SE
Independent variable						
Constant	−4.286*	0.984	2.620*	0.363	2.487*	0.249
Indicator for sex[2]					0.022*	0.006
Dubowitz,[3] w	1.068*	0.249	0.285*	0.094	0.168*	0.064
Maternal prepregnancy BMI,[3] kg/m^2	0.274*	0.104	0.094*	0.038	0.101*	0.026
Maternal hemoglobin,[3] g/l	0.136	0.093	−0.013	0.034	0.033	0.023
Maternal hookworms/g[3]	−0.014	0.009	−0.007*	0.003	−0.004	0.002
Parity	0.007	0.005	−0.0003	0.0019	0.012*	0.0004
Parity squared					−0.0008*	0.0004
Indicator for birth order 1	−0.102*	0.051	−0.007	0.019		
Infant age, days			0.002*	0.0004	0.002*	0.0004
Adjusted R^2	0.33		0.27		0.51	
Sample size, n	102.0		99.0		99.0	

[1] Values are slope coefficients ± standard errors.
[2] Boy, 1; girl, 0.
[3] These variables and the dependent variable were in logarithms; coefficients of these explanatory variables are elasticities.
* $P < 0.05$.

RESULTS

Results for birth weight, length, and head circumference

The results for birth weight, and length and head circumference measured few days after birth, are reported in Table 1. Maternal prepregnancy BMI, hemoglobin concentration, and hookworms were transformed into natural logarithms (Nelson et al., 1989). Estimated coefficients of these variables were thus the elasticities (proportionate change in the dependent variable resulting from 1% change in the independent variable). The models were also estimated with variables in levels. Coefficients significant at the 5% level were marked with asterisks.

There were several noteworthy features of the results. First, the elasticity of birth weight with respect to gestation period exceeded unity (birth weight was approximately 200 g less than the 50th U.S. percentiles; National Center for Health Statistics, 1977). The point estimates of elasticities of infant length and head circumference with respect to gestation period were, respectively, 0.29 and 0.17. Thus, longer gestation periods had the greatest impact on birth weight, followed by length and head circumference. The elasticity of birth weight with respect to the maternal prepregnancy BMI was 0.27 ($P < 0.05$). Thus, good initial nutritional status was associated with higher birth weight. Hookworm intensity was negatively associated with birth weight, though the coefficient was not significant at the 5% level ($P = 0.077$). The indicator (0–1) variable for first-born infants showed a lower birth weight ($P < 0.05$). However, the number of live births (parity) was not significantly associated with birth weight. This was also true for the square of parity (see below).

The prepregnancy BMI was statistically significant ($P < 0.05$) in the relationships for length and head circumference measured a few days after birth. The point estimate of the elasticities was close to 0.10. Because the infants were measured at slightly different ages, age in days was included as a regressor; age was a significant predictor ($P < 0.05$) of length and head circumference. The coefficients of the indicator variable for first-born infant and the parity variable were not statistically significant in the model for infant length. The overall fit of the model for length was worse than that for weight and head circumference. This could be due to the fact that infant length at birth is often not very different for undernourished and affluent populations (Karlberg et al., 1994). Thus, it is more difficult to relate observed differences in maternal characteristics to infant length.

Sex of the infant was not significant in the models for birth weight and length, but was significant in the model for head circumfer-

TABLE 2. Regressions models explaining the scores on Reflex, Habituation, Orientation, and Motor clusters of Brazelton Neonatal Behavioral Assessment Scale by maternal nutritional status and demographic characteristics[1]

Dependent variable	Reflex[2]		Habituation[3]		Orientation		Motor	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Independent variable								
Constant	−6.241	9.766	4.297	5.809	2.272	5.267	6.614	2.627
Dubowitz, w	0.048	0.151	0.016	0.087	0.041	0.082	0.019	0.041
Maternal prepregnancy BMI, kg/m^2	−0.179	0.116	0.102	0.069	0.088	0.062	0.073*	0.031
Infant BMI, kg/m^2	−0.089	0.215	0.087	0.129	−0.107	0.116	−0.025	0.058
Infant head circumference, cm	0.493	0.269	0.161	0.158	−0.035	0.145	−0.156*	0.072
Infant arm circumference, cm	−0.449	0.412	−0.023	0.247	0.132	0.222	0.190	0.111
Adjusted R^2	0.003		0.028		−0.008		0.068	
n	85.0		74.0		85.0		85.0	

[1] Values are slope coefficients ± standard errors.
[2] Reflex was the cluster based on 18 elicited responses.
[3] Habituation, Orientation, and Motor clusters were defined by Lester et al. (1986).
* $P < 0.05$.

ence, indicating that boys had a greater head circumference than girls. The relationship between parity and head circumference was a quadratic one, and both terms were significant ($P < 0.05$). However, the coefficient of the indicator variable for first-born was not significant in this model. Maternal hookworms infestation was estimated with a negative sign that was not significant at 5% level. However, hookworm intensity was a significant predictor ($P < 0.05$) of infant length.

The effects of maternal weight gain and sicknesses during the three trimesters on birth weight, length, and head circumference were investigated using the models in Table 1. However, these variables were not statistically significant. This partly reflected the difficulties in identifying sicknesses that affect fetal growth. Spells of mild undernutrition during the pregnancy may not be as important as, for instance, the general maternal health status represented by variables such as BMI, hemoglobin concentration, and hookworm infestation. While hemoglobin was not an important predictor in the results in Table 1, it was significant in certain versions of the model. However, socioeconomic variables were not significant predictors of anthropometric measurements, presumably because such factors were reflected in maternal health status.

Results for scores on the Brazelton NBAS

The empirical models explaining the scores on the Reflex, Habituation, Orientation, and Motor clusters of the Brazelton NBAS are presented in Table 2 (the results for Range, State, Autonomic Stability, and Mean Score were similar and hence were omitted). It was evident, however, that the explanatory variables did not explain the variation in scores. The R-squared (adjusted for degrees of freedom) were often close to zero and assumed slightly negative values for some models. Coefficients of some explanatory variables were statistically significant. For example, maternal prepregnancy BMI was positively associated with scores on the Motor cluster. But in this model, infant head circumference had a negative coefficient that was significant ($P < 0.05$). Moreover, the results were not robust to changes in model specification; statistical significance of explanatory variables seemed more due to chance than a substantive finding.

The poor fit of the model for scores on the Brazelton NBAS raised the issue of validity of the scores. First, one could question the reliability of the tests; infants might have scored differently if tested at another point in time. The role of within-subject variation in test scores can be investigated by designing studies that repeatedly test infants over a few days. However, multiple observations on the Brazelton NBAS would be expensive. Furthermore, using averages as dependent variables may not improve the fit of the models.

Second, genetic and cultural factors may have influenced scores on the Brazelton NBAS. A comparison of Kenyan infants' scores with those for other populations might reveal some unusual aspects of the study. In

TABLE 3. Sample means and standard deviations of the scores on Brazelton Neonatal Behavioral Scale clusters for Kenyan, Puerto Rican, and African American infants[1]

	Kenya		Puerto Rico[2]		U.S.[3]	
Country	Mean	SD	Mean	SD	Mean	SD
Variables						
Reflex	3.757	2.501	2.050			
Habituation	4.980	1.481	7.050		7.400	1.060
Orientation	4.323	1.352	4.850		6.020	1.550
Motor	4.497	0.651	4.050		5.330	0.740
Range	3.704	0.983	3.850		3.830	0.740
Regulation of State	5.112	1.126	5.700		5.900	1.260
Autonomic Stability	5.494	0.685	6.950		6.920	1.160
n	115.0		37.0		228.0	

[1] Values are means ± standard deviations.
[2] From Lester et al. (1982), SD not reported by the authors.
[3] From Oyemade et al. (1994).

Table 3, the mean scores of Kenyan infants on the seven clusters are presented along with the results for 228 African-American infants (Oyemade et al., 1994) and for a sample of 37 infants from Puerto Rico (Lester et al., 1986); the latter researchers did not report standard deviations.

The mean scores on the clusters were similar for the three populations, though there were some differences. Kenyan infants appeared to do worse than their counterparts in Puerto Rico and U.S. on most clusters. On Motor Development, however, the scores were slightly better for Kenya than for Puerto Rico. The estimated standard deviations for Kenyan and U.S. infants were of a similar order of magnitude. For example, the coefficients of variation for the Motor cluster for Kenya and the U.S. were, respectively, 0.145 and 0.139. It would seem reasonable to conclude that the Brazelton NBAS was appropriately designed for the Kenyan population. This, however, does *not* imply that scores on the Brazelton NBAS were useful indicators of infant development in the Kenyan population. It might be preferable to use anthropometric indicators for identifying vulnerable children at early ages. However, this argument is conditional on the assumption that the scores on the Brazelton NBAS were poor predictors of later psychological outcomes. Because the infants took the Bayley scales at 6 months, this issue is discussed below.

Results for the dynamics of infant length in the period of 1–6 months

The empirical results for infant length are presented in Table 4. With the exception of indicator variables for sex and the survey periods, the explanatory variables were transformed into logarithms. Coefficient of the sex indicator variable was significant ($P < 0.05$), showing that boys were slightly longer than girls. Maternal BMI and hemoglobin concentration were positively associated with infant length, though the coefficients were not significant at the 5% level. Calcium intake from weaning was positively associated with length ($P < 0.05$); calcium intakes were positively associated with height in a Filipino sample (Bhargava, 1994)

TABLE 4. Maximum likelihood estimates of dynamic random effects model for infant length in the period from 1–6 months explained by maternal nutritional status, and infant nutrient intakes and morbidity[1,2]

	Length (cm)	
Dependent variable	Coefficient	SE
Independent variable		
Constant	2.466*	0.224
Sex[3]	0.009*	0.003
Maternal hemoglobin,[4] g/L	0.011	0.013
Maternal BMI,[4] kg/m^2	0.025	0.015
Infant calcium intake,[4] mg/day	0.001*	0.0006
Infant morbidity index[4]	−0.0001	0.0008
Indicator time period 3	0.024*	0.005
Indicator time period 4	0.041*	0.007
Indicator time period 5	0.061*	0.009
Indicator time period 6	0.068*	0.011
Lagged dependent variable,[4] cm	0.356*	0.059
Between/within-variance	0.564*	0.161
Within-variance	0.0006	
Chi-square (6)[5]	9.52	
2× log-likelihood function	−4,375.03	
n	102.0	

[1] Values are slope coefficients ± standard errors.
[2] The 102 infants were observed six times at monthly intervals.
[3] Boy, 1; girl, 0.
[4] These variables and the dependent variable were in logarithms.
[5] Chi-square is the likelihood ratio test statistic for exogeneity of morbidity index; degrees of freedom = 6.
* $P < 0.05$.

TABLE 5. Maximum likelihood estimates of dynamic random effects model for infant head circumference in the period from 1–6 months explained by maternal nutritional status, and infant nutrient intakes, morbidity, and length[1,2]

Dependent variable and model	Head circumference (cm)			
	Specification 1		Specification 2	
	Coefficient	SE	Coefficient	SE
Independent variable				
Constant	0.479*	0.185	1.516*	0.121
Sex[3]	0.007*	0.002	0.015*	0.002
Maternal hemoglobin,[4] g/l	0.018	0.011	0.031*	0.011
Maternal head circumference,[4] cm	0.136*	0.048	0.225*	0.016
Maternal BMI,[4] kg/m^2	−0.0002	0.009	0.008	0.012
Maternal morbidity index[4]	−0.0006	0.0005	−0.0003	0.0006
Infant morbidity index[4]	−0.0003	0.0006	−0.0007	0.0006
Infant length,[4] cm	0.211*	0.033		
Indicator time period 3			0.016*	0.003
Indicator time period 4			0.037*	0.005
Indicator time period 5			0.049*	0.006
Indicator time period 6			0.052*	0.007
Lagged dependent variable,[4] cm	0.475*	0.039	0.298*	0.052
Between/within-variance	0.268*	0.088	1.040*	0.216
Within-variance	0.0003		0.0003	
Chi-square[5]	18.83		8.98	
2× log-likelihood function	−4,371.85		−4,845.03	
n	92.0		102.0	

[1] Values are slope coefficients ± standard errors.
[2] The 92 infants were observed six times at monthly intervals.
[3] Boy, 1; girl, 0.
[4] These variables and the dependent variable were in natural logarithms.
[5] Likelihood ratio statistics in Specifications 1 and 2 test, respectively, the exogeneity of infant morbidity and length, and infant morbidity (degrees of freedom, 12 and 6, respectively).
* $P < 0.05$.

and also for school-age children from this Kenyan population (Bhargava, 1999).

Indicator variables for the 4 survey months were estimated with significant positive coefficients ($P < 0.05$); these estimates confirmed steady growth during the 1–6-month period (at most four such indicator variables can be included). Coefficient of the lagged dependent variable was significant ($P < 0.05$); the long-run elasticity of length with respect to an explanatory variable was approximately 1.5 times the short-run elasticity reported in Table 4. For example, doubling an infant's calcium intake was associated with a 1% increase in infant length in a short time frame. The long-run impact would be to increase length by 1.5%. While the magnitude of these elasticities was small, length is known to respond very gradually to nutritional intakes.

The between/within-variance ratio was significant ($P < 0.05$) in the model for length. Thus, unobserved between-infant differences played an important role in this model. Note that many other explanatory variables were also introduced into the dynamic model. However, the coefficients of households' socioeconomic status and cash income, maternal morbidity and hookworms, parity, parents' scores on cognitive tests, an index for the duration of breast feeding, etc., were not significant predictors of infant length.

Results for the dynamics of infant head circumference in the period of 1–6 months

The results for head circumference presented in Specification 1 of Table 5 showed that boys had a greater head circumference than girls, which was also the case for measurements just after birth (Table 1). The elasticity of infant head circumference with respect to maternal head circumference was 0.14 ($P < 0.05$). Paternal head circumference was not a significant predictor, which could be due to the greater number of missing observations on the fathers that had lowered the sample size used in the estimation. Maternal BMI, hemoglobin concentration, and morbidity and infant morbidity were not significant predictors of head circumference.

Infant length was a significant predictor ($P < 0.05$) of head circumference in Specification 1 in Table 5; systemic bone growth is likely to increase cranial vault thickness (Lieberman, 1996). However, in Specification 2 of Table 5, length was dropped from the model to allow for possible differences in the mechanisms governing cranial and long bone growth. While the four indicator variables for time periods were not significant in Specification 1, they were significant in Specification 2, presumably because increase in length partly accounted for the growth in head circumference in Specification 1. Moreover, in contrast with the results for Specification 1, maternal hemoglobin concentration was a significant predictor of infant head circumference in Specification 2. Thus, maternal iron status appears to have had a beneficial effect on the growth in infant head circumference in the period of 1–6 months. The between/within-variance ratio was large in Specification 2, presumably indicating that omitting length from the model led to an increase in the unobserved between-infant differences. Likelihood ratio statistics accepted the null hypothesis that the random effects affecting length and morbidity were uncorrelated with those affecting head circumference.

Results for the dynamics of infant weight in the period from 1–6 months

The results for infant weight are in Table 6. The indicator variable for sex was not significant in this model. Maternal BMI and hemoglobin concentration were significant predictors of growth in weight in the period of 1–6 months ($P < 0.05$). This presumably reflected the fact that the breast milk of well-nourished mothers contained greater quantities of fat and possibly other nutrients that enhance infant growth (Jelliffe and Jelliffe, 1978; Brown et al., 1986). However, other indicators of maternal nutritional status such as protein intakes and skinfold thicknesses were not significant predictors of infant weight. Paternal BMI was also not significantly associated with infant weight.

Infant sicknesses were negatively associated ($P < 0.05$) with body weight; arm circumference and length were significant predictors ($P < 0.05$) of weight. The use of length to predict body weight is common in the anthropometric assessment literature (Ehrenberg, 1968; Tanner, 1986; Cole, 1991). However, because the arm circumference is an approximation for lean body tissue, its inclusion greatly improved the fit of the model for weight (Bhargava, 1999). In contrast with the results for length and head circumference, the between/within-variance ratio was not significant in the model for weight; unobserved between-infant differences were apparently accounted for by explanatory variables such as length and arm circumference.

The results from estimating dynamic models for the z-scores for weight-for-age, based on the tabulations for the U.S. (National Center for Health Statistics, 1977) and the U.K. (Freeman et al., 1995), are presented in Table 7. Four indicator variables were included in the model for the time periods. Infant length and arm circumference were omitted from the set of explanatory variables; previous z-score was treated as an endogenous variable in the estimation. Maternal BMI and hemoglobin concentration and some of the time indicator variables

TABLE 6. Maximum likelihood estimates of dynamic random effects model for infant weight in the period from 1–6 months explained by maternal nutritional status, and infant nutrient intakes, morbidity, and length and arm circumference[1,2]

Dependent variable	Weight (kg) Coefficient	SE
Independent variable		
Constant	−5.066*	0.545
Sex[3]	0.006	0.008
Maternal hemoglobin,[4] g/l	0.077*	0.026
Paternal BMI,[4] kg/m^2	0.023	0.025
Maternal BMI,[4] kg/m^2	0.087*	0.019
Maternal morbidity index[4]	0.0009	0.0026
Infant calcium intake,[4] mg	0.002	0.002
Infant morbidity index[4]	−0.006*	0.002
Infant arm circumference,[4] cm	0.666*	0.060
Infant length,[4] cm	0.973*	0.118
Lagged dependent variable,[4] kg	0.283*	0.039
Between/within-variance	0.008	0.047
Within-variance	0.0061	
Chi-square (18)[5]	24.14	
2× log-likelihood function	−2,469.18	
n	81.0	

[1] Values are slope coefficients ± standard errors.
[2] The 81 infants were observed six times at monthly intervals.
[3] Boy, 1; girl, 0.
[4] These variables and the dependent variable were in logarithms.
[5] Likelihood ratio statistic tests the exogeneity of infant morbidity, arm circumference, and length; degrees of freedom = 18.
* $P < 0.05$.

TABLE 7. Maximum likelihood estimates of dynamic random effects model for z-scores for weight-for-age based on NCHS and U.K. reference standards explained by maternal nutritional status, and infant nutrient intakes[1,2]

Dependent variable, with model	z-scores for weight-for-age			
	NCHS standards[3]		U.K. standards[4]	
	Coefficient	SE	Coefficient	SE
Independent variable				
Constant	−8.381*	2.480	−8.134*	1.684
Maternal hemoglobin,[5] g/l	0.021*	0.007	0.016*	0.004
Paternal BMI,[5] kg/m^2	0.069	0.060	0.051	0.040
Maternal BMI,[5] kg/m^2	1.757*	0.778	1.880*	0.516
Maternal morbidity index[5]	−0.007	0.042	0.011	0.027
Infant calcium intake, mg/day[5]	0.023	0.036	0.023	0.022
Infant morbidity index[5]	−0.050	0.041	−0.023	0.028
Indicator time period 3	−0.051	0.182	−0.120	0.114
Indicator time period 4	−0.553*	0.184	−0.339*	0.117
Indicator time period 5	−0.238	0.190	−0.456*	0.120
Indicator time period 6	−0.293	0.192	−0.486*	0.119
Lagged dependent variable,[5] cm	−0.037	0.052	0.284*	0.056
Between/within-variance	0.310*	0.104	0.417*	0.139
Within-variance	1.465		0.586	
2× log-likelihood function	−300.26		160.18	
n	90.0		90.0	

[1] Values are slope coefficients ± standard errors.
[2] The 90 infants were observed six times at monthly intervals.
[3] National Center for Health Statistics (1977).
[4] Freeman et al. (1995).
[5] These variables and the dependent variable were in natural logarithms.
* $P < 0.05$.

were significantly associated with the z-scores for weight-for-age. However, the lagged dependent variable was not significant in the model based on the National Center for Health Statistics (NCHS) reference standards. Also, infant morbidity index was not significantly associated with the z-scores for weight-for-age. Overall, the results in Table 6 and 7 were similar. However, the dynamic model for infant weight incorporated the interrelationships between total body weight, skeletal size (length), and lean body tissue (arm circumference), while addressing the issues of endogeneity of certain explanatory variables. This approach was in the spirit of previous contributions to the anthropometric assessment literature (Tanner, 1986; Ehrenberg, 1968; Cole, 1991).

Results for scores on Bayley Motor Scale and Bayley Infant Behavior Record

The results for scores on the Bayley Motor Scale are reported for three specifications in Table 8. Specification 2 replaced the infants' protein intakes with protein intake from animal sources that has been used as an indicator of diet quality in Kenya (e.g., Neumann et al., 1992). Specification 3 included mean scores on the Brazelton NBAS as an explanatory variable. The scores on the Bayley Motor Scale were positively associated ($P < 0.05$) with protein intake and arm circumference. In Specification 2, protein intake from animal sources was a significant predictor ($P < 0.05$). Infant morbidity was negatively associated with the scores, though the coefficient was not significant at the 5% level ($P = 0.10$). Infant length, weight, and head circumference were not significant predictors of motor development.

The four interaction variables (look, touch, hold, and talk), measuring mother-infant interaction were not significant predictors of scores on the Bayley Motor Scale. In Specification 3, the coefficient of the mean score on the Brazelton NBAS was estimated with a negative sign but was not significant. This was also true when the mean score was replaced by the score on the Motor cluster of the Brazelton NBAS. Thus, the scores on the Bayley Motor Scale were better predicted by infants' nutritional and health status. Early psychological measures lacked the predictive power to warn clinicians and policy makers of potential developmental problems.

The results for scores on eight items from the Bayley Infant Behavioral Record in Table

TABLE 8. Regression models explaining scores on Bayley Motor Scale at 6 months by infants' nutritional status, morbidity, and mean score on the Brazelton Neonatal Behavioral Assessment Scale[1,2]

Dependent variable, with model	Score on 33 items from the Bayley Motor Scale					
	Specification 1		Specification 2		Specification 3	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Independent variable						
Constant	−0.028	8.321	0.819	8.181	2.379	10.222
Infant protein intake, g/day	0.126	0.071			0.131	0.083
Infant animal protein intake, g/day			0.209*	0.088		
Infant length, cm	0.075	0.137	0.078	0.135	0.036	0.168
Infant arm circumference, cm	0.840*	0.292	0.790*	0.285	0.952*	0.361
Infant morbidity index	−0.007	0.004	−0.007	0.004	−0.008*	0.004
Mean score on Neonatal Behavioral Assessment Scale					−0.281	0.608
Adjusted R^2	0.107		0.129		0.088	
n	100.0		100.0		82.0	

[1] Values are slope coefficients ± standard errors.
[2] The number of items on which the infants passed the test.
* $P < 0.05$.

TABLE 9. Regression models explaining scores on eight items from the Bayley Infant Behavior Record at 6 months by infants' nutritional status, morbidity, and mean score on the Brazelton Neonatal Behavioral Assessment Scale[1,2]

Dependent variable, with model	Score on eight items from Bayley Infant Behavior Record					
	Specification 1		Specification 2		Specification 3	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Independent variable						
Constant	10.438	11.231	13.178	11.555	7.524	12.964
Maternal interaction (talk)	11.195*	4.367	12.049*	4.499	10.860*	4.955
Infant protein intake, g/day	0.297*	0.097			0.334*	0.107
Infant animal protein intake, g/day			0.209	0.124		
Infant length, cm	−0.004	0.184	0.003	0.190	0.083	0.213
Infant arm circumference, cm	1.093*	0.399	0.930*	0.408	1.122*	0.467
Infant morbidity index	0.001	0.006	0.001	0.006	−0.001	0.006
Mean score on Neonatal Behavioral Assessment Scale					−0.516	0.792
Adjusted R^2	0.173		0.118		0.192	
n	100.0		100.0		82.0	

[1] Values are slope coefficients ± standard errors.
[2] The items were Endurance, Activity, Banging toys, Manipulating, Body Motion, Energy and Coordination, Coordination of Gross Muscle Movement, and Coordination of Fine Muscle.
* $P < 0.05$.

9 showed protein intake and arm circumference to be significant predictors ($P < 0.05$). In contrast with the results for the Bayley Motor Scale, time spent by the mother talking to the infant was a significant predictor of scores. The remaining three interaction variables were not significant. Infant morbidity was not significant in the three specifications in Table 9. The total protein intake was a significant predictor of the scores. The fit of the models left a substantial amount of variation in the data unexplained. This is likely to be a common feature in the analysis of psychological data collected at an early age, partly due to within-subject variation.

Nevertheless, the results for the Bayley scales were an improvement over those for the Brazelton NBAS. Even so, variables such as maternal anthropometric indicators were not significant predictors of scores on the Bayley scales.

DISCUSSION

This paper studied in detail the proximate determinants of anthropometric and psychological measures of Kenyan infants from birth to age 6 months. The analysis used infant birth weight, and length and head circumference, as indicators of the intrauterine growth environment. The scores on the Brazelton NBAS were analyzed, and the dynamics of physical growth in the period from 1–6 months was investigated by modeling infant length, head circumference, and

weight. Lastly, the scores on Bayley Motor Scale and the Bayley Infant Behavior Record were analyzed.

There are several implications of the empirical results. First, maternal nutritional status was an important predictor of infants' anthropometric measurements at birth. Mothers with a high prepregnancy BMI and free from hookworm infestation were likely to produce babies that were longer, heavier, and with a larger head circumference. Parity was associated with anthropometric measurements in a nonlinear way. Thus, supplying fortified foods to undernourished pregnant women is likely to be beneficial for infant health.

Second, the scores on the Brazelton NBAS for the Kenyan infants were not systematically associated with the measures of maternal or infant nutritional status. A comparison of the results for Kenyan infants with those for African American and Puerto Rican infants suggested that, even in undernourished populations such as those from the Embu region, the Brazelton NBAS may not facilitate identification of vulnerable children. This is partly because maternal undernutrition and infection did not appear to have caused neurological defects in Kenyan infants; the Brazelton NBAS may be useful in identifying such problems. Because the Brazelton NBAS is expensive to administer, it would not seem cost-effective to examine infants in sub-Saharan Africa using this test.

Third, the dynamic models for length, head circumference, and weight, estimated using data from 1–6 months, showed that maternal nutritional status, and infant nutrition and morbidity, were important factors predicting growth. For example, maternal hemoglobin was positively associated with infant weight and head circumference, maternal BMI was positively associated with infant length and weight, maternal head circumference was a predictor for infant head circumference, infants' calcium intakes were positively associated with length, and infant morbidity was negatively associated with weight. Because the longitudinal analysis controlled for many confounding factors affecting growth, the empirical results underscored the importance of good maternal nutritional status for infant growth.

Fourth, the analysis of scores on the Bayley Motor Development Scale and eight items from the Bayley Infant Behavior Record showed that nutritional status was positively associated with higher scores on the tests. Moreover, the analysis offered insights into the usefulness of arm circumference as a measure for identifying vulnerable children. The quality of diet was an important predictor of scores on the Bayley scales. However, care is needed in interpreting this finding, because weaning can increase the risk of infection (e.g., Mata, 1978).

Finally, because psychological measures for young infants may not be very reliable, the physical and mental development of children should be approached in an integrated framework. It is important for researchers to jointly utilize anthropometric and psychological data for identifying vulnerable children in developing countries. While anthropometric measures were seen to be better indicators of early development, the scores on cognitive tests of school-age children from this population were informative from a policy viewpoint (Bhargava, 1998).

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